RESEARCH DEPARTMENT

H.F. bridge receiver/oscillator, Mark 3

TECHNOLOGICAL REPORT No. RA-5

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THE BRITISH BROADCASTING CORPORATION
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RESEARCH DEPARTMENT

H.F. BRIDGE RECEIVER/OSCILLATOR, MARK 3

Technological Report No. RA-5
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H.F. BRIDGE RECEIVER/OSCILLATOR, MARK 3

SUMMARY

This report describes a unit in which an oscillator, covering the frequency range 3·5 to 30 MHz, is mechanically ganged to a receiver covering the same range. This unit is intended to be used in association with an admittance bridge for measurements on aerial and feeder systems at high-frequency transmitting stations.

1. INTRODUCTION

At high-frequency (h.f.) transmitting stations it is necessary from time to time, either as a routine check or in making changes or repairs, to measure and adjust the admittances of aerials and feeder systems. These measurements may have to be made in the presence of high-power h.f. transmissions, sometimes on a frequency quite close to the measuring frequency, and this places a rather severe requirement on the screening and selectivity of the receiver used with the r.f. admittance bridge.

The equipment has to be battery-operated, as a mains supply is not usually available at the point where measurements are made. It is operationally very convenient if the equipment is readily portable. The apparatus used hitherto[1] consists of separate oscillator and receiver units and has performed very well since 1943. There are, however, several disadvantages:

(a) The equipment is bulky and heavy. The total weight of the oscillator, bridge, receiver and power supplies, is about 45 kg. (100 lbs.).

(b) There is insufficient adjacent-channel rejection.

(c) The receiver sensitivity is somewhat low, although adequate for bridging with the oscillator employed.

(d) There is no a.g.c. in the receiver, and it tends to saturate so that frequent use of the manual gain control is needed.

(e) The oscillator and receiver are not directly calibrated in frequency.

In view of these disadvantages, it was considered desirable to design new equipment, making use of the advantages offered by transistors.

2. OPERATIONAL REQUIREMENTS AND DESIGN CONSIDERATIONS

The requirements may be summarized as follows:

(a) The equipment should be portable, rugged and stable, and have self-contained power supplies.

(b) The frequency range should cover the broadcast bands between 3·95 MHz and 26·1 MHz. The frequency calibration should be direct reading, with an accuracy of 1%.

(c) The receiver should provide audible and visual indication of signal strength.

(d) The oscillator power and receiver sensitivity must be sufficient to give a precise indication of the "balanced" position of the controls of an admittance bridge.

(e) The receiver should be suitable for use separately, e.g. with a measuring loop, if required.

(f) The screening and selectivity should be such as to permit measurements to be made in the presence of high-power transmissions, at least in other h.f. bands and, if possible, in the same band.

3. CHOICE OF SYSTEM

As the signal source and receiver are normally used together, it is an operational advantage if a single tuning control can be used. There are several possible systems, as follows:

3.1. A Superheterodyne with Locked Signal Source

This employs a single variable oscillator and a fixed oscillator at the intermediate frequency

(i.f.). The variable oscillator is used as the receiver local oscillator, and is also mixed with the fixed oscillator to produce the signal source. The r.f. circuits are tracked with the variable oscillator, and must reject the i.f. and image signals. One disadvantage of this system is that the signal output will tend to be low, unless considerable r.f. amplification is used.

3.2. A Locked Superheterodyne with Oscillator as Source

This is similar to system 3.1, but in this case the output signal is obtained directly from a variable oscillator, while the receiver local-oscillator frequency is obtained by beating with the fixed i.f. oscillator. The local-oscillator frequency requires filtering with tracked circuits. As with system 3.1, good isolation of the i.f. oscillator from the i.f. amplifier is needed.

3.3. A Single-Span Locked Superheterodyne

This is similar to 3.1, but the i.f. is raised to a frequency above the top of the h.f. band, and the receiver input circuit would consist of a wideband filter, with the upper cut-off frequency between the highest input frequency and the i.f. The i.f. may be further frequency-changed, if desired. There are no ganging or tracking problems with this system, but there would be undue sensitivity to intermodulation or blocking, and a need for a double superhet system to achieve the required i.f. selectivity.

3.4. A Synchronous Detection System

In this case, one variable oscillator is used for the output signal and for the receiver local oscillator; there is therefore no intermediate frequency. In this system, a varying phase shift through the bridge during a measurement would produce errors unless a continuous phase rotation is introduced into the local oscillator path, so as to provide an a.f. tone output.

3.5. Oscillator with Ganged Tuned-R.F. Receiver

In this case, the oscillator and receiver are electrically separate, but the tuning is mechanically ganged. The receiver selectivity would tend to be poor, and it might be difficult to achieve adequate sensitivity.

3.6. Oscillator with Ganged Superheterodyne Receiver

As in 3.5, the oscillator and receiver are electrically separate, and the tuning is mechanically ganged. Good selectivity and sensitivity can be obtained in the i.f. amplifier, but problems of tracking are greater than in the case of 3.5.

Consideration was given to each of the above systems and 3.6 was finally chosen as being the best practical arrangement.

4. MECHANICAL CONSTRUCTION

In the interest of portability and operational convenience it is desirable that the oscillator, bridge and receiver, together with battery power supplies, should be housed in one unit. However, there are practical reasons why it may sometimes be useful to have the bridge separate from the oscillater and receiver, and this also simplifies the design problems, so it was decided to omit the bridge and to house only the oscillator and receiver, with their power supplies and an indicating meter in the one unit.

A photograph of the complete unit is shown in Fig. 1, while Fig. 2 shows the equipment withdrawn from its case. The equipment is built in a framework supported on a 14 B.G. (2·00 mm) steel front panel and fitted into an 18 S.W.G. (1·25 mm) steel case, with a 16 S.W.G. (1·60 mm) aluminium alloy lid. The oscillator and the receiver are in separate screened boxes and are aligned so that their tuning capacitors and range switches have common spindles. The re-chargeable batteries are mounted between the two. The power switching is arranged so that the oscillator and receiver can be switched on singly or together. The case is fitted with adjustable feet, so that the unit can be tilted if required. A leather carrying strap is provided, which can be easily removed if desired. The total weight is 16 kg. (35 lbs.).

The meter is normally clipped to the front panel, but it can be readily detached for operational convenience.

5. CHOICE OF RECEIVER I.F. AND FREQUENCY RANGES

In choosing the i.f., the normal considerations such as selectivity and image rejection must be taken into account, but in the present application it is also particularly desirable to ensure that with the wanted signal lying within any broadcast band, signals in other broadcast bands should not form image responses. With these considerations in mind, the i.f. selected is 1·55 MHz.

The choice of the number of switched r.f. ranges employed is a compromise between circuit complexity and tracking difficulties. Four ranges were finally selected to cover approximately the following frequencies:

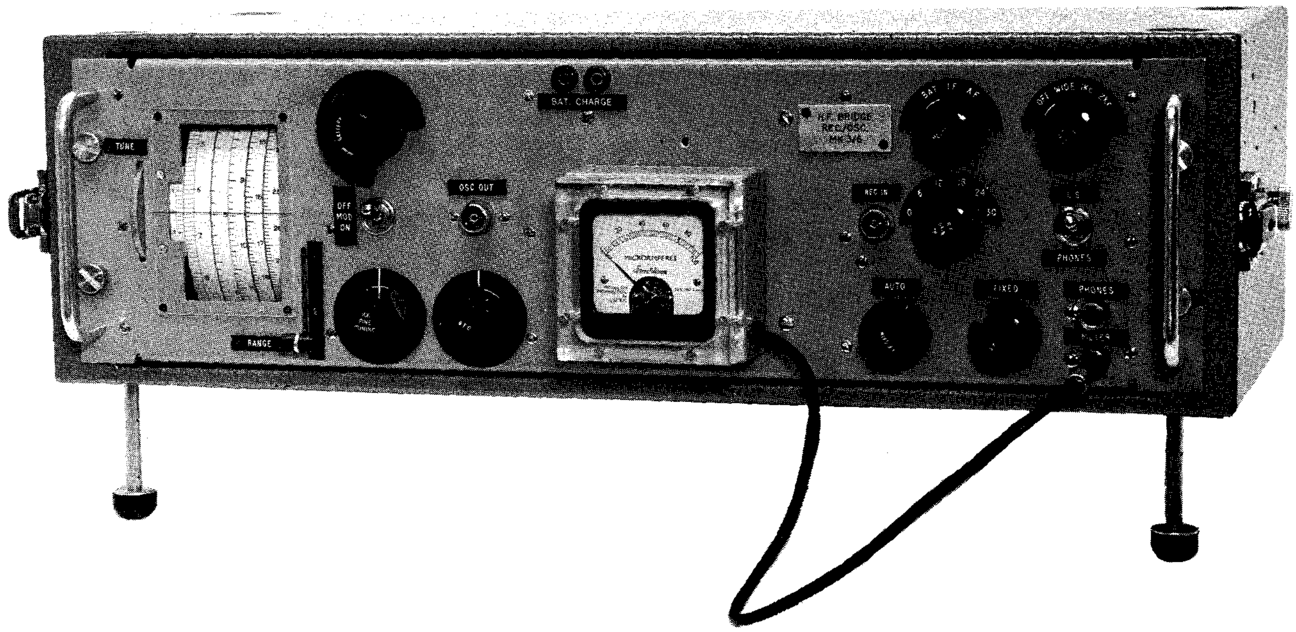

Fig. 1 - H.F. Bridge Receiver/Oscillator: front view

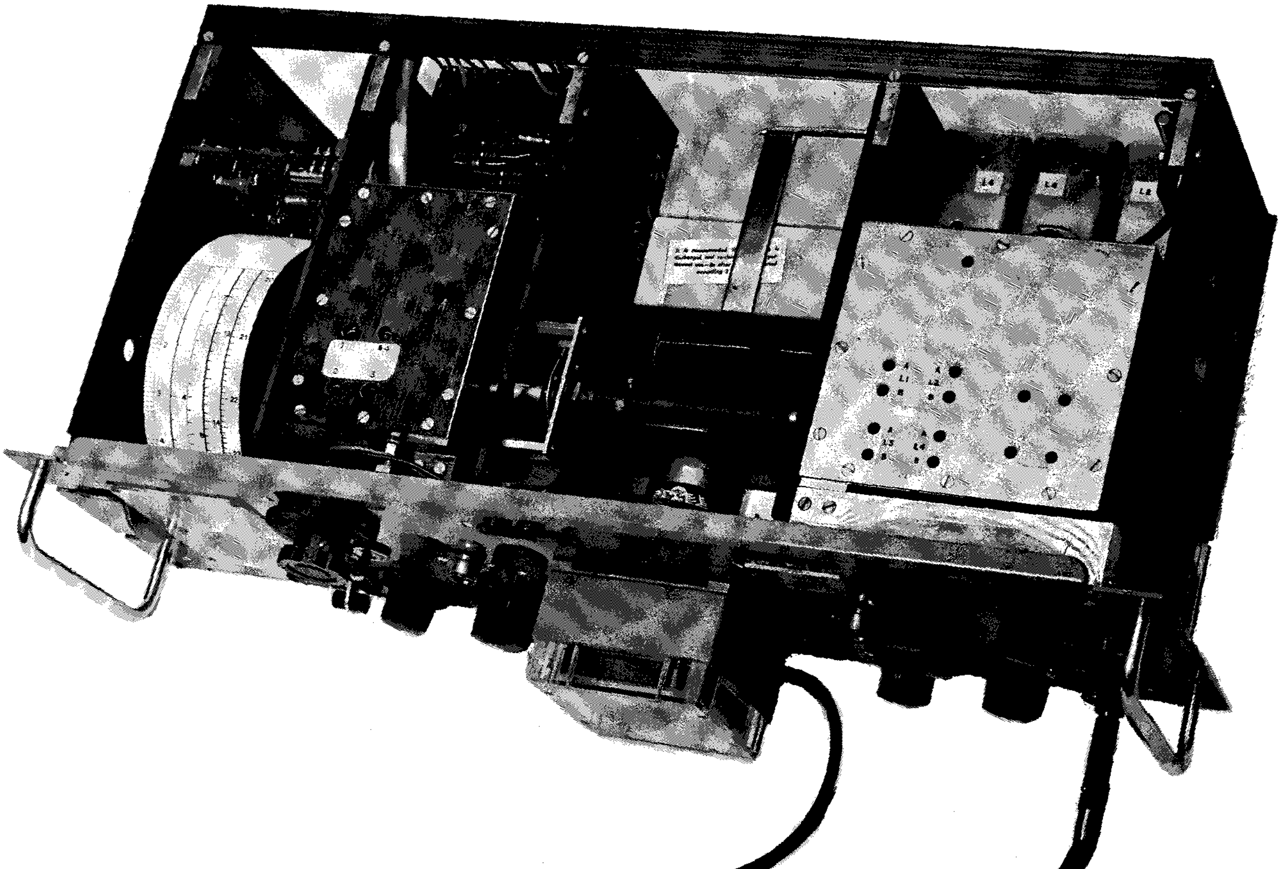

Fig. 2 - H.F. Bridge Receiver/Oscillator:. case removed

Range 1:	3·5 to 7·0 MHz	75 and 49 metre bands
Range 2:	7·0 to 12·5 MHz	41, 31 and 25 metre bands
Range 3:	12·5 to 20·0 MHz	19 and 16 metre bands
Range 4:	20·0 to 30·0 MHz	13 and 11 metre bands

It may be noted that with these ranges, every broadcast band lies completely within a range. It is seen that the frequency coverage is complete from 3·5 MHz to 30 MHz, although for normal requirements only the broadcast bands need be included. It was thought, however, that there would be no significant advantage in providing a discontinuous frequency coverage. Also, it can sometimes be of value to measure impedances at frequencies beyond the broadcast band limits.

6. DESCRIPTION OF CIRCUITS

6.1. Bridge Oscillator

The circuit is given in Fig. 3. TR1 is the maintaining amplifier of the oscillator, and this is followed by a two-stage wideband amplifier providing a low-impedance output. The amplifier also acts as a buffer stage, reducing the effect of load variations upon the oscillator frequency. The d.c. conditions of TR1 are stabilized against ambient temperature changes by means of a thermistor, TH, in the base-bias circuit, together with the emitter resistors. TR1 works in the common-emitter configuration, the tuned circuit being connected between collector and emitter. The feedback voltage to the base is obtained from a wideband transformer, T1, connected in parallel with the tuned circuit. This arrangement was adopted to reduce the amount of switching required; another winding on T1 is used to connect the output from TR1 to the input of the wideband amplifier.

The CR circuits in the emitter of TR1 provide phase correction which was found to be necessary to allow for the circuit wiring inductance. These were adjusted experimentally to obtain as uniform an output as possible over the required frequency range. The capacitor in the base circuit improves the output at high frequencies.

The output from T1 is followed by a switched attenuator, the purpose of which is to help equalize the range-to-range variation in output.

The diodes D1 and D2 are used for modulation by a 2 kHz oscillator. With no applied modulating voltage, D1 is biased in the forward direction, while D2 is cut off, and the r.f. oscillator output is applied with very little loss to the input of the wideband amplifier. When a modulating voltage is applied, the effective resistance of D1 is increased, and that of D2 is decreased, so that modulation of the r.f. input to the wideband amplifier takes place. The linearity of the modulation is poor, but in the present application this is unimportant.

The wideband amplifier consists of a series-feedback stage followed by a shunt-feedback stage. It has a voltage gain of about 14 from the input base to the output collector.

The transformer T2 is used to transform the load impedance to a suitable value for the amplifier. As the load is not constant, the turns ratio of T2 is necessarily a compromise. The ratio has been chosen so that the distortion introduced by the amplifier is negligible for load impedances above 75Ω. For lower impedances, clipping of the waveform will occur.

6.2. 2 kHz Modulation Oscillator

As shown in Fig. 3, the single-transistor oscillator has a parallel-T feedback network, arranged in a form proposed by Emms[2], and is followed by a buffer amplifier. The open-circuit voltage is about 3·2V r.m.s.

6.3. The Receiver

The receiver can be considered as divided into six units, as follows:

(1) R.F. input attenuator

(2) R.F. tuned circuits and amplifier

(3) Local Oscillator

(4) Mixer and first i.f. amplifier

(5) Main i.f. amplifier, b.f.o. and detector

(6) Audio amplifier

6.3.1. R.F. Input Attenuator

The attenuator (Fig. 4) is designed to work between 100Ω impedances and is switchable in five 6 dB steps from 0 to 30 dB. The actual receiver and source impedances will not in general be exactly 100 ohms, so that the calibration of the attenuator can only be regarded as approximate.

6.3.2. R.F. Tuned Circuits and Amplifier

In order that the receiver may be used in the presence of local high-power transmissions, it is desirable to have as much r.f. selectivity as possible before any non-linear components, such

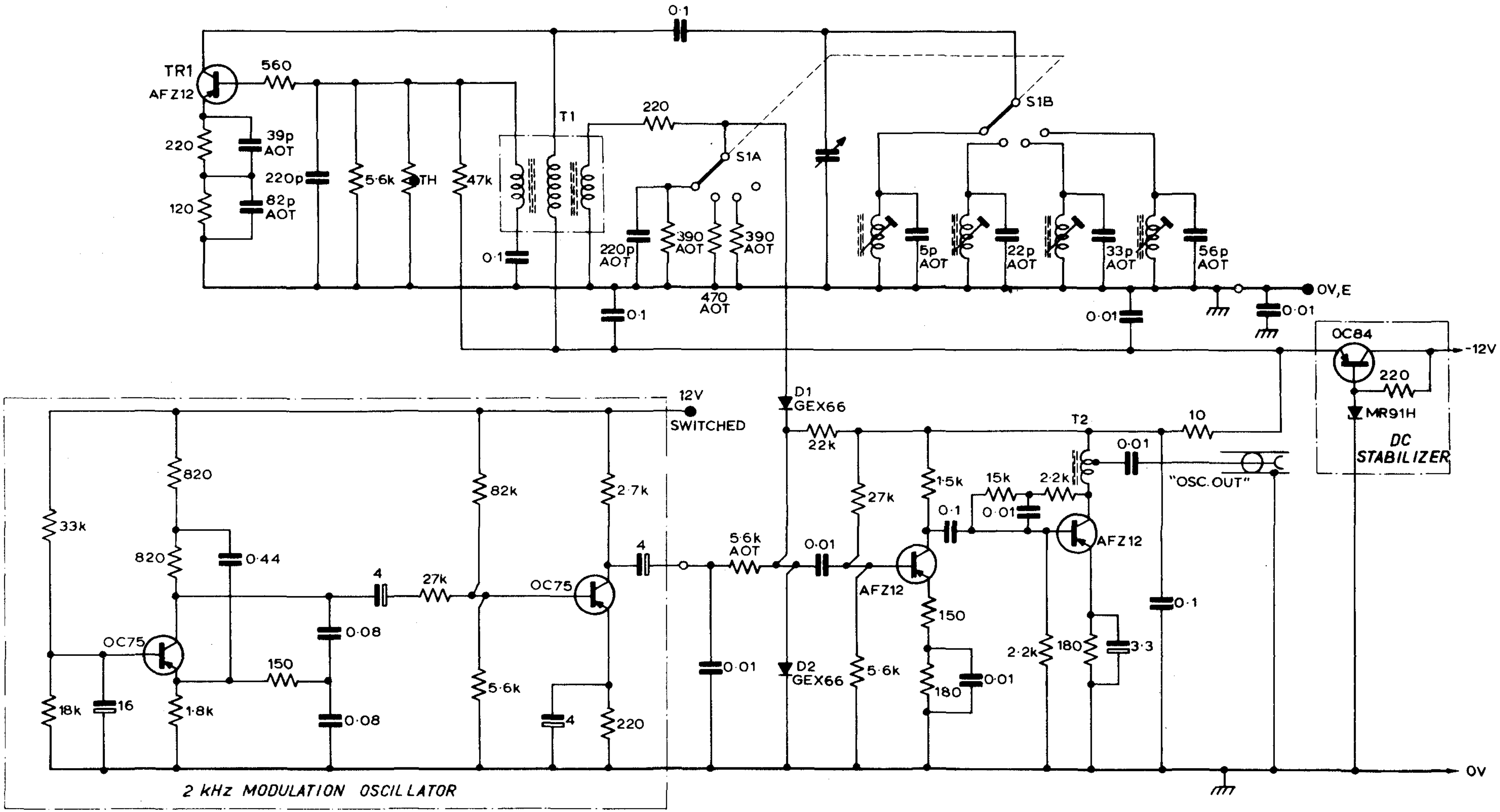

Fig. 3 - Oscillator and Modulator Circuit Diagram

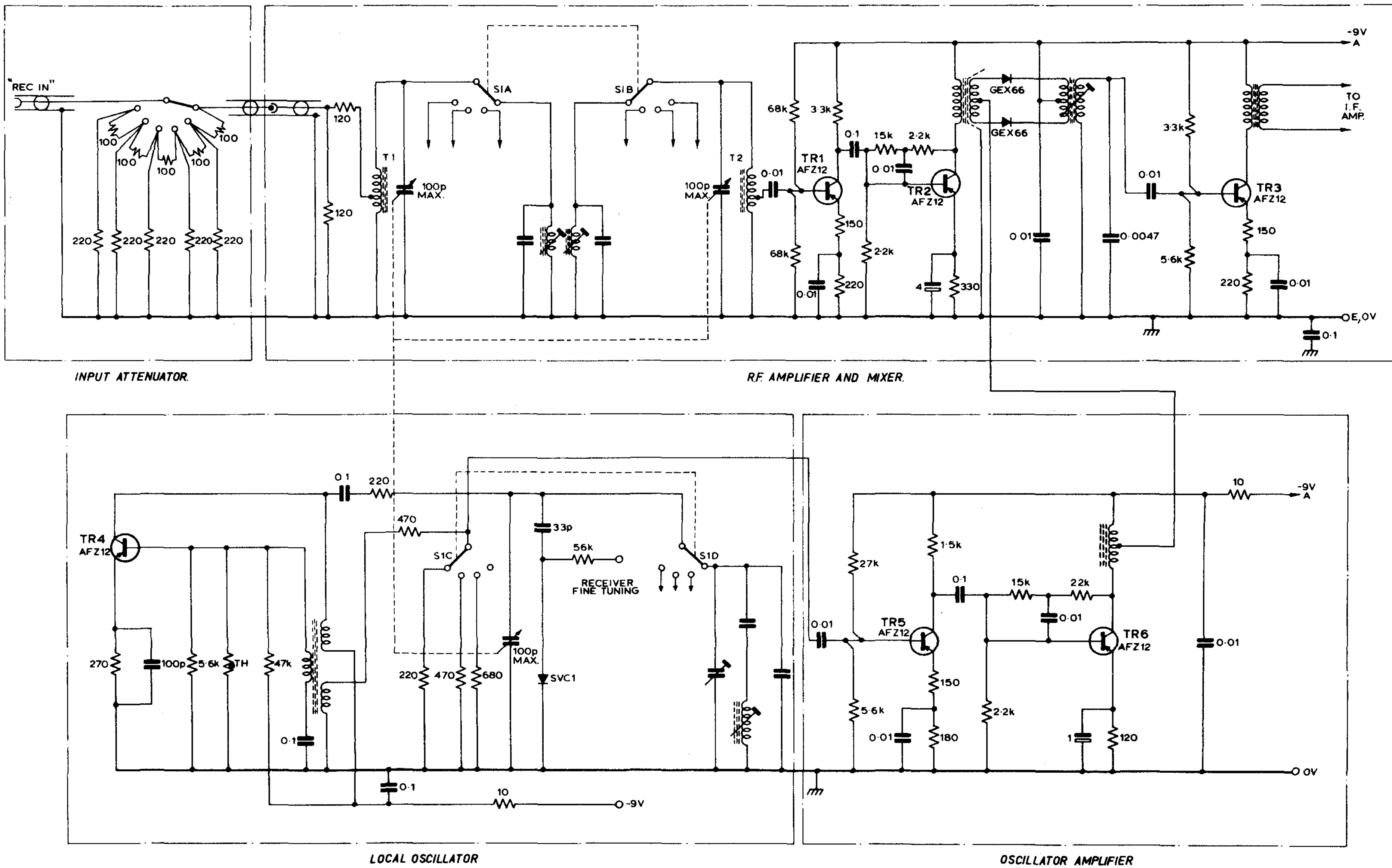

Fig. 4 - Receiver Circuit Diagram (R.F. Amplifier and Mixer)

as transistors. For this reason, a coupled pair of tuned circuits is used at the receiver input, and this is followed by a wideband feedback amplifier.

Referring to Fig. 4, a resistive pad helps to ensure that the tuned circuits are fed from a mainly resistive impedance. The wideband transformers, T1 and T2, couple the source and the amplifier to the tuning capacitors of the primary and secondary circuits, respectively. This arrangement avoids the need for switched tappings on each coil; only one switch is required for each circuit for the connection to the tuning capacitors.

The design of the tuned circuits is necessarily a compromise between achieving high selectivity and high efficiency. No specification had been laid down giving the selectivity requirements, and the criterion adopted was that the image rejection should be at least 40 dB.

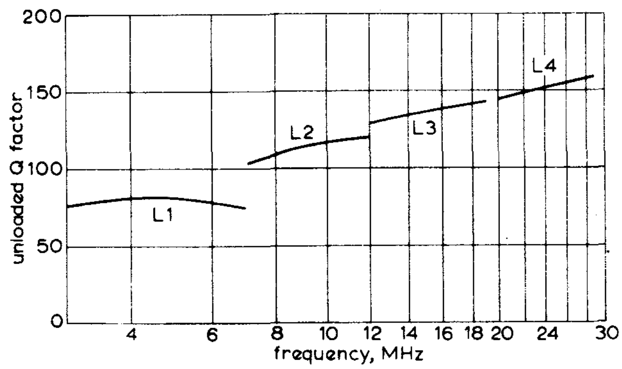

Fig. 5 - Receiver R.F. Circuits: Unloaded Coil Q/Frequency

Fig. 5 shows the measured variation with frequency of the unloaded Q-factor of the r.f. coils. Using these values of Q, and calculating the mean loaded Q, the insertion loss of the selective circuits (compared with a wide-band match) is found to be as shown in Fig. 6, assuming critical coupling at the frequencies of maximum Q. The broken curves in Fig. 6 show that the loss contributed by the wideband transformers is less than 3 dB. The voltage gain of the r.f. amplifier is about 14.

6.3.3. The Local Oscillator

The design of the local oscillator is basically the same as that of the bridge oscillator, and it incorporates a similar wideband amplifier. There are, however, some differences in layout, making possible a simpler phase-correcting circuit in the emitter. The local oscillator also incorporates a variable-capacitance diode, which is used as a fine frequency control to correct for errors in tracking with the bridge oscillator. There are padding capacitors in series with the tuned-circuit coils

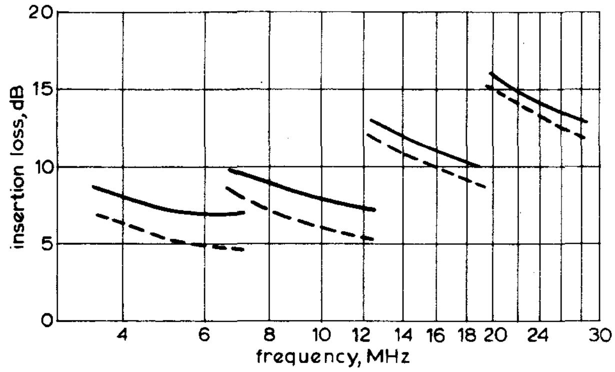

Fig. 6 - Receiver R.F. Circuits: Insertion Loss/ Frequency

——— Calculated loss, including loss in wideband transformers

– – – Calculated loss, assuming no loss in wideband transformers

to achieve nominally three-point tracking but, at the higher frequencies, the error in the frequency difference between the local oscillator and the bridge oscillator is caused more by unavoidable differences in the tuning capacitors etc., than by the theoretical tracking errors.

Consideration was given to providing a built-in crystal oscillator/multiplier for checking the frequency calibration. It was thought, however, that calibration checks would not usually need to be carried out in the field and an entirely separate unit was produced for frequency checking when required; this unit is not described here.

6.3.4. Mixer and First I.F. Amplifier

The mixer is a diode circuit which is balanced in order to reduce coupling between the signal and local oscillator circuits. It is followed by one stage of i.f. amplification; the output is then fed to the main i.f. amplifier unit.

6.3.5. Main I.F. Amplifier, B.F.O. and Detector

The main 1·55 MHz i.f. amplifier (Fig. 7) consists of two common-emitter stages. The input and interstage tuned circuits consist of critically-coupled double-tuned pairs, while the output circuit is single-tuned with inductive coupling to the detector.

The gain of the amplifier is controlled by a voltage applied to the base of the first stage, causing the collector voltage to bias a diode which alters the damping across the input circuit. The control voltage is supplied from a potentiometer for manual control, or from a hybrid detector circuit for a.g.c.

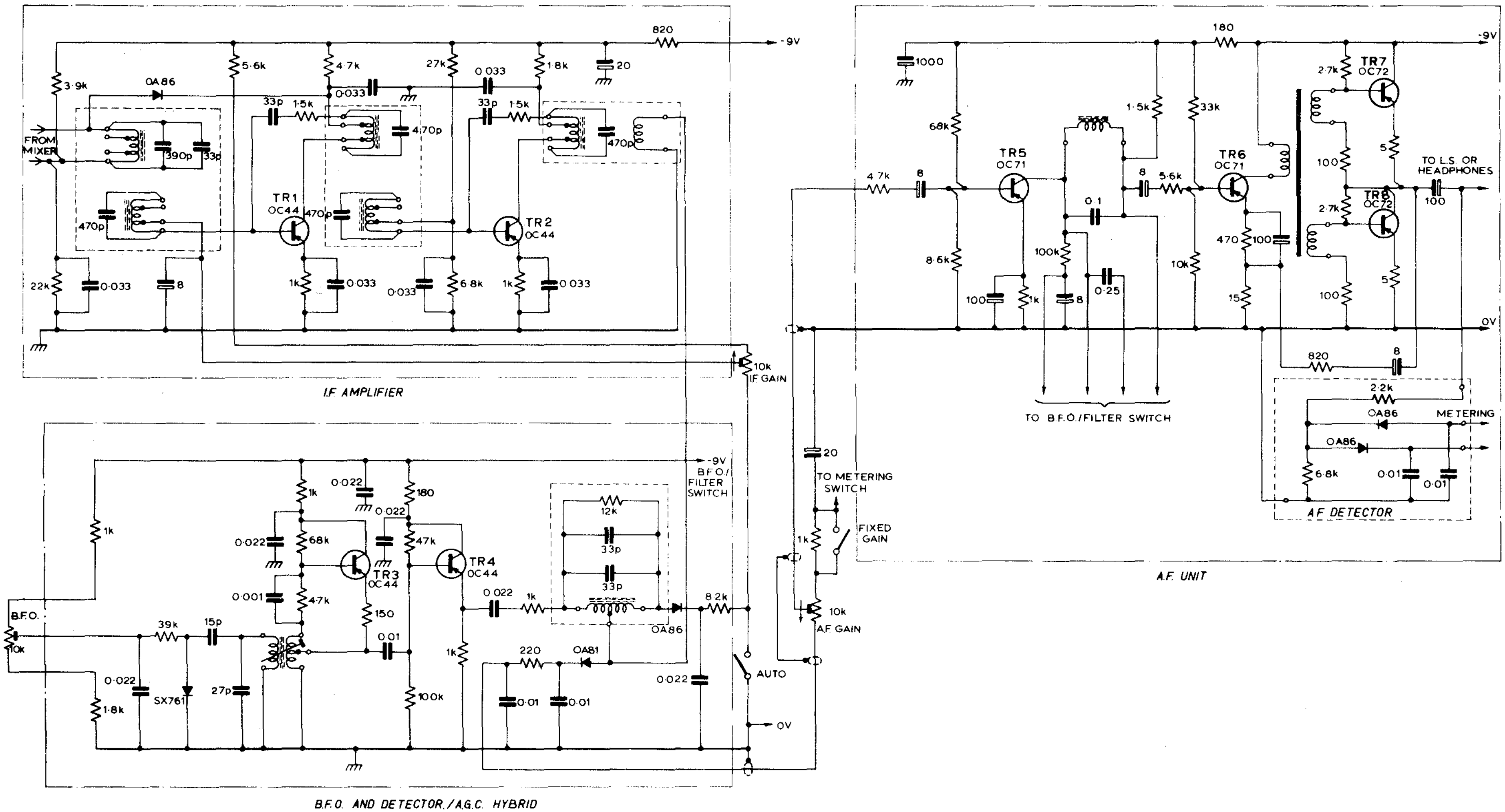

Fig. 7 - Receiver Circuit Diagram (I.F., B.F.O. and A.F. Units)

The b.f.o. and a.g.c. hybrid circuit is incorporated within a separate screened section in the i.f. chassis. The b.f.o. oscillates in an emitter-coupled, tuned-base configuration. A variable-capacitance diode is used to provide a variation of about ± 12 kHz in the b.f.o. frequency. The output from the b.f.o. is fed via an emitter follower buffer stage to the a.g.c. hybrid circuit. The purpose of this circuit is to isolate the b.f.o. from the a.g.c. detector, at the same time allowing the i.f. and b.f.o. outputs to intermodulate in the a.f. detector; Fig. 8 shows a simplified diagram of the circuit.

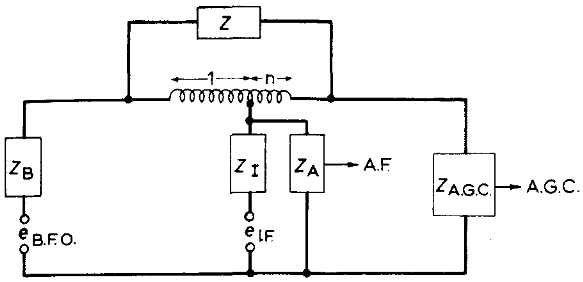

Fig. 8 - Detector/A.G.C. Hybrid : Simplified Circuit

Analysis shows that if:

$$Z = \frac{(n+1)^2}{n} \cdot \frac{Z_I \cdot Z_A}{Z_I + Z_A},$$

then e_{BFO} produces no voltage across Z_{AGC}. In addition, if $Z_{AGC} = nZ_B$, then e_{IF} is isolated from the Z terminals. In the present case, n = ½.

6.3.6. Audio Amplifier*

The amplifier, when switched to wideband conditions, is a straightforward circuit delivering up to 230 mW into a 35Ω loudspeaker. For full output it requires an input of 20 mV. It is also provided with a narrow-band filter, switchable to 1 kHz or 2 kHz, connected between the first two stages. With the filter in circuit, the gain of the amplifier is increased by about 10 dB.

The input to the amplifier is obtained from the a.f. detector, either through a variable potentiometer, or, in the "fixed gain" position, from a fixed tapping point. The voltage across the loudspeaker can be metered by means of a full-wave rectifier circuit.

Headphones can replace the loudspeaker via a jack socket, if desired.

6.4. D.C. Supplies

Power for the equipment is obtained from two 6 volt nickel-cadmium re-chargeable batteries connected in series. The capacity of the batteries is 1·5 ampere-hours, when discharged over a period of 10 hours. The total battery voltage should not be allowed to fall below 11 volts. A warning mark is provided on the meter which is used with the equipment, to indicate when re-charging is required. Two sockets are mounted on the front panel for connection to a suitable battery charger. The charging current should not normally exceed 150 mA. A trickle charge of up to 20 mA can be safely applied for about 100 hours.

The battery current consumption with the receiver and oscillator switched on, but with the modulation and b.f.o. off is about 80 mA. With modulation on and with the a.f. gain at maximum this rises to about 120 mA.

The 2 kHz modulation oscillator is supplied directly from the battery, but the rest of the equipment is fed via three simple stabilizers, each providing a nominal output of 9 volts. The output impedance of each stabilizer is less than 1 ohm, and an input voltage change of 20% produces an output voltage change of less than 1·5%.

7. PERFORMANCE

7.1. Bridge Oscillator

The following information relates to the prototype model; production models may differ slightly in performance.

7.1.1. Frequency Range

3·5 to 30 MHz, in four ranges, as follows:

Range 1	:	3·5 to 6·9 MHz
Range 2	:	6·8 to 12·5 MHz
Range 3	:	12·3 to 20·1 MHz
Range 4	:	19·8 to 30·0 MHz

7.1.2. Output

The open-circuit output voltage variation with frequency is shown in Fig. 9.

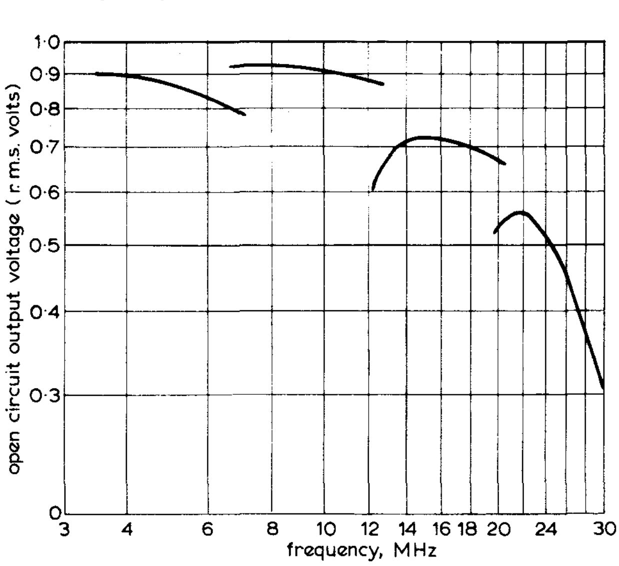

Fig. 9 - Oscillator Output Voltage/Frequency

* Initial design work for the a.f. amplifier and filter was carried out by M.W. Greenway.

7.1.3. Output Impedance

Approximately 30 ohms.

7.1.4. Harmonic Distortion

At 5 MHz and 10 MHz there is approximately 10% third harmonic distortion. The second harmonic is very small. At higher frequencies the third harmonic is reduced.

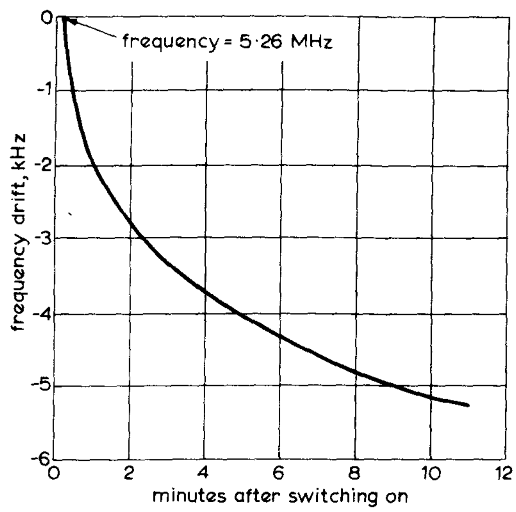

Fig. 10 - Oscillator Frequency Drift

7.1.5. Frequency Stability

Fig. 10 shows the frequency drift during the first eleven minutes after switching on at initial frequency of 5·26 MHz. After a quarter of an hour, the frequency drifts by less than 1 kHz. The temperature-dependence is such that over a temperature range of 22 to 45°C the frequency drift on each range is less than 1·2 parts in 10^4 per °C.

Although the frequency drift was not measured at lower temperatures, the performance was checked at -5°C and found entirely satisfactory. The load dependence is such that the frequency changes by less than 5 parts in 10^4 at all frequencies when the load changes from an open-circuit to 47 ohms; at most frequencies the change is less than 2 parts in 10^4.

7.2. Receiver

7.2.1. Sensitivity

Fig. 11 shows measured values of sensitivity, defined as the input required, at maximum gain, to produce a meter reading of 2μA when indicating the i.f. detector current.

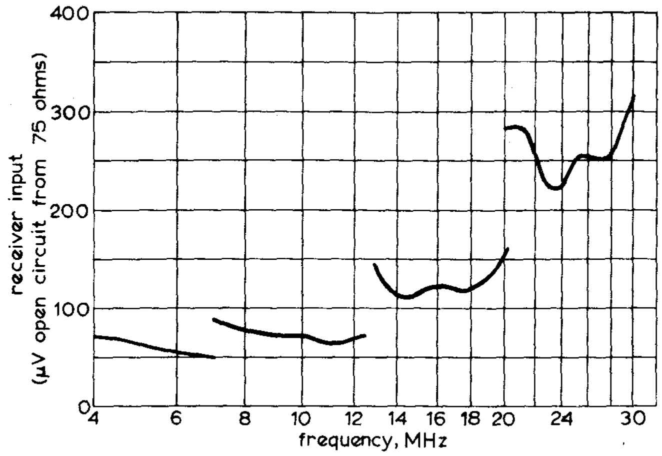

Fig. 11 - Receiver Sensitivity/Frequency

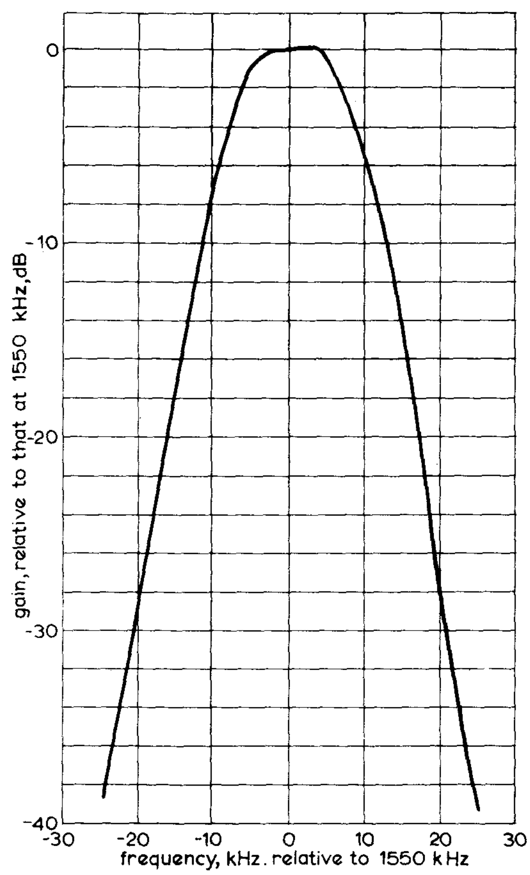

Fig. 12 - Receiver Selectivity : Overall Response/Frequency

7.2.2. Selectivity

Fig. 12 shows an overall selectivity curve, measured at 10 MHz.

7.2.3. Image Rejection

Fig. 13 shows measured values of image rejection. It may be seen that the target of 40 dB has been achieved at most frequencies.

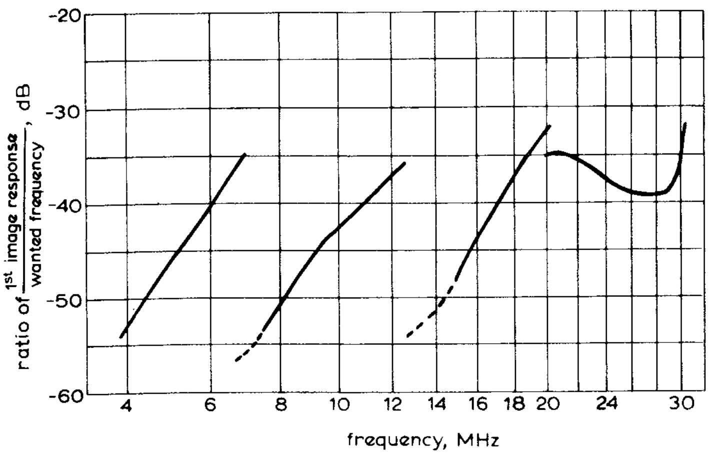

Fig. 13 - Receiver Image-Frequency Rejection/Frequency

_ _ _ _ Subject to measuring inaccuracy

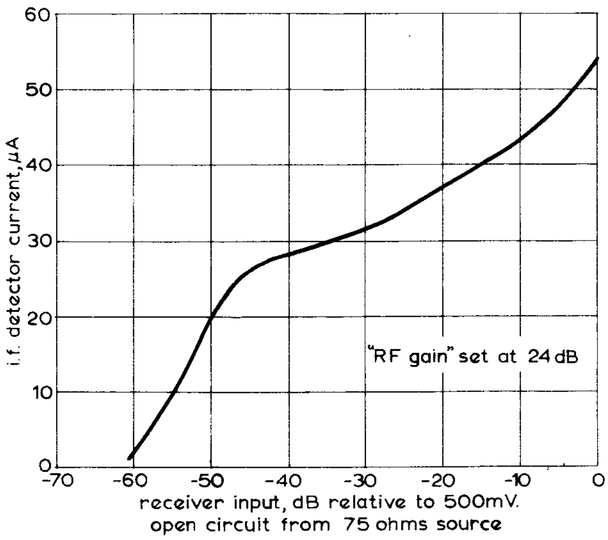

Fig. 14 - Receiver A.G.C. Characteristics

7.2.4. A.G.C. Characteristic

Fig. 14 shows the output meter reading (i.f. detector current) as a function of the input signal level when operating with a.g.c. This characteristic is suitable for a bridge receiver since, even when the input is large because the bridge is badly misbalanced, changes in receiver output with input variations are sufficient to indicate an approach towards balance.

7.2.5. Audio-frequency Response

Fig. 15 shows the frequency response of the audio amplifier.

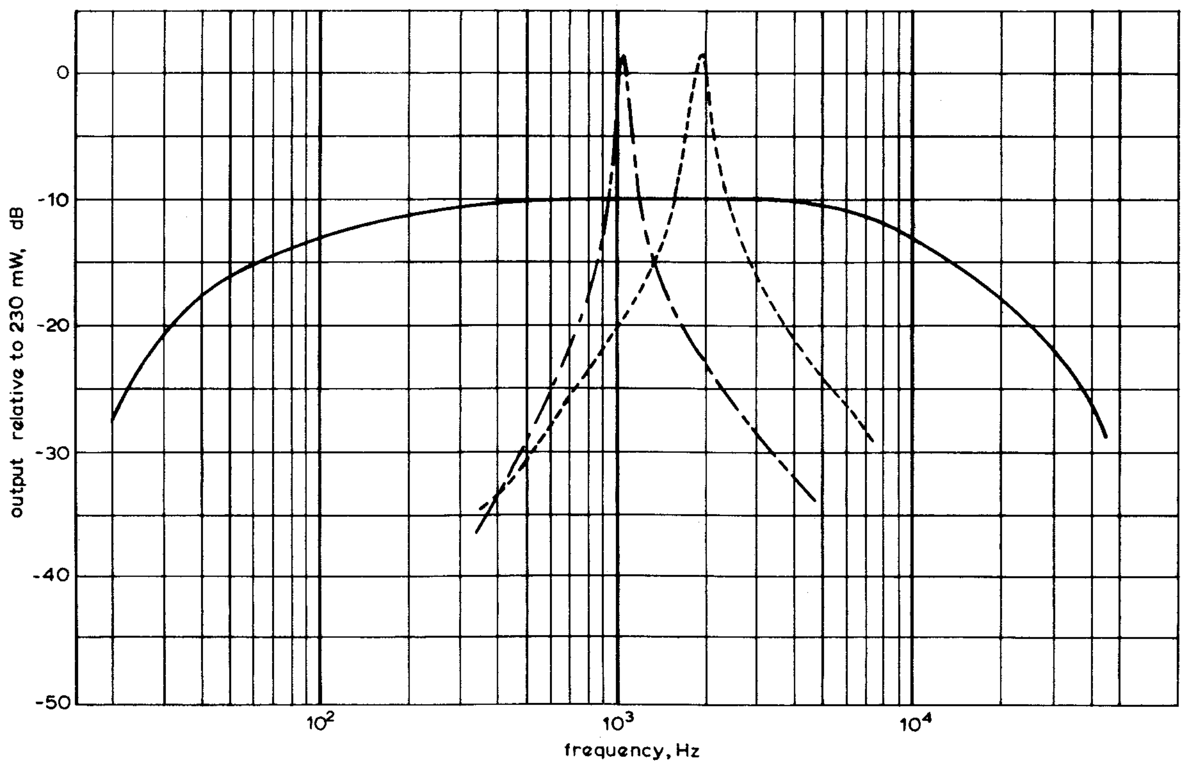

Fig. 15 - Receiver A.F. Response/Frequency

——— Wideband condition

— — — 1 kHz filter in circuit

- - - - 2 kHz filter in circuit

8. CONCLUSIONS

A ganged h.f. oscillator/receiver has been designed and, in conjunction with an admittance bridge, has given a satisfactory performance during field trials at a h.f. transmitting station. Although some difficulties were experienced in obtaining sufficiently well-matched components for the r.f. circuits, eight further units have been produced and successfully aligned. Some of the desirable features were conflicting, such as lightness and ruggedness, power output and consumption, screening and accessibility. A reasonable compromise has been made between these requirements in the present design but a fresh design, using the experience gained and with modern components, might well differ in a number of ways.

9. REFERENCES

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